

Decline of Red Spruce in the
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16. ABSTRACT Thirty-two stands in the spruce-fir forests of Whiteface Mountain in the Adirondacks, originally sampled from 1964-66, were resurveyed in 1982. From 10-25 Bitterlich points were used in each stand in 1982 to obtain an estimate of basal area per hectare. Data were summarized for low elevation (< 900m) and high elevation (≥ 900m) forests. Red spruce declined by 40-60% in basal area for the low elevation forests and by 60-70% above 900m. Balsam fir decreased by 35% at high elevations, due to natural disturbance in several of the stands, but was unchanged when only undisturbed stands were considered. The decline of red spruce accounted for about three quarters of the total decrease in basal area for both the high and low elevation forests. Spruce seedling frequency for the high elevation sample decreased by 80%, but was unchanged below 900m. The pattern of spruce decline in the Adirondacks is similar to findings for New England. The cause of the decline is speculative at this time. <i>1984 Torrey Botanical Club. Copyright (c)</i>		
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Decline of red spruce in the Adirondacks, New York¹

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Key words: *Picea rubens*; Adirondacks, New York; decline; montane boreal forest.

From qualitative observations there has been wide concern that the species red spruce (*Picea rubens* Sarg.) has declined in the montane forests of the northeastern U.S. Siccama *et al.* (1982) documented this decline quantitatively on Camels Hump and other regions of the Green Mountains in Vermont. Johnson and Siccama (1983) presented evidence that the decline is extensive in other parts of New England and New York. The cause of the decline of spruce

is not known but has been discussed by Siccama *et al.* (1982), Vogelmann (1982), Johnson and Siccama (1983) and Tomlinson (1982, 1983).

We present here quantitative evidence of the spruce decline on Whiteface Mountain in the Adirondacks of New York.

On Whiteface Mountain the vegetation consists of several broad types governed mainly by elevation. The low elevation sites (below about 700m) consist largely of northern hardwoods dominated by sugar maple (*Acer saccharum* Marsh.), beech (*Fagus grandifolia* Ehrh.) and yellow birch (*Betula alleghaniensis* Britt.). From 700m to 900m a transition forest occurs grading into spruce-fir, which ranges up to about 1100m. Above 1100m the forest is nearly pure balsam fir. Spruce-fir forests also exist at low elevations in bogs or on some sloping sites (usually facing west).

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Methods. From 1964–1966, 184 forested stands on or near Whiteface Mountain (44° 17'N, 73° 48'W) were studied by Holway and Scott (1969). From 10 to 50 sampling points were used in each stand to obtain measures of density, basal area and frequency for the canopy species. All of the sites were on Whiteface Mountain or in nearby foothills or lowlands. Red Spruce occurred in 143 of the stands and represented 16% of the total relative importance, reaching its maximum importance at about 900m. The original stand selection was systematic, with the goal being to find samples of mature forests for all altitudes and a complete range of slope aspect. Aerial photographs were used to find undisturbed forest sites at elevations separated by 150m intervals which were then examined in the field. If the site was of relatively uniform slope and slope aspect and contained mostly mature forests it was sampled. For the re-survey in the summer of 1982 we chose stands which: (1) had considerable amounts of red spruce in the original survey, (2) were relatively easy to find, and (3) included a range of altitude and slope aspect.

Basal area ($m^2 ha^{-1}$) was measured using Bitterlich Prisms. Diameter at 1.2m of each tree which fell within the prism was measured. Ground flora and tree seedling frequency were obtained from 10 one m^2 quadrats in each stand. Ten points were taken with the 2.5 metric prism, but in six cases where a 6.4 metric prism was used 20 to 25 points were measured. In all cases 25 paces were taken between points and the slope and aspect of the original survey were maintained. If changes in slope aspect occurred, the team moved up or down slope 50 paces and reversed directions as in the 1964–66 study.

The degree of confidence in locating the original stands was designated as (1) certain, (2) highly confident, and (3) uncertain. For those stands in category (1) the original field notes and maps were very specific about how to find the stand. Usually a road, trail or stream was used to designate a starting point at a given elevation. The altimeters in both surveys were accurate enough to measure elevation to within $\pm 10m$. Often the original field notes contained maps of features such as slides,

bluffs, erratic boulders, changes in slope aspect, etc. which were found in the re-survey. To be ranked in category (1) the mean slope aspects of the two surveys had to agree to within 10 degrees and was measured at every point in the stand in both surveys. Most were within 5 degrees.

Stands were ranked in category (2) when the original field notes were clear enough, but when no obvious feature could be used to locate the starting point. In these cases the mean slope aspect of the two surveys agreed to within 10 degrees.

The "uncertain" category (3) was used for a variety of reasons. In three cases the mean slope aspects of the two surveys differed by greater than 20 degrees. In two, new ski slopes were constructed on the site of the original stand and the nearest forested area at the same elevation was sampled. In three the original field notes were unclear and a feature designating the starting point was not available. In two stands the species composition of the vegetation or the tree size was different from the original with no obvious disturbance between surveys. Of the 32 stands which were re-surveyed 13, 9 and 10 were included in categories (1), (2) and (3), respectively.

Results. There is a natural concern that the re-survey data may be suspect because of inability to find the original sites and because natural disturbance could affect many of the stands. The latter might favor species such as balsam fir (*Abies balsamea* (L.) Mill.) or cordate-leaved birch (*Betula papyrifera* var. *cordifolia* (Regel) Fern.) over red spruce causing the indicated spruce decline to be spurious. We present data in various sub-samples in an attempt to show that the spruce decline is unequivocal. We include only data on dominance ($BA ha^{-1}$) because the inclusion of density data, although measured in both surveys, does not lead to different conclusions.

Data in Fig. 1 and Table 1 are for stands in the 900 to 1100m spruce-fir forests and those in Table 2 are for low-lying sites: including two bogs, five west or north-facing spruce-fir sites, and five low-lying northern hardwood stands where spruce was a major component of the original

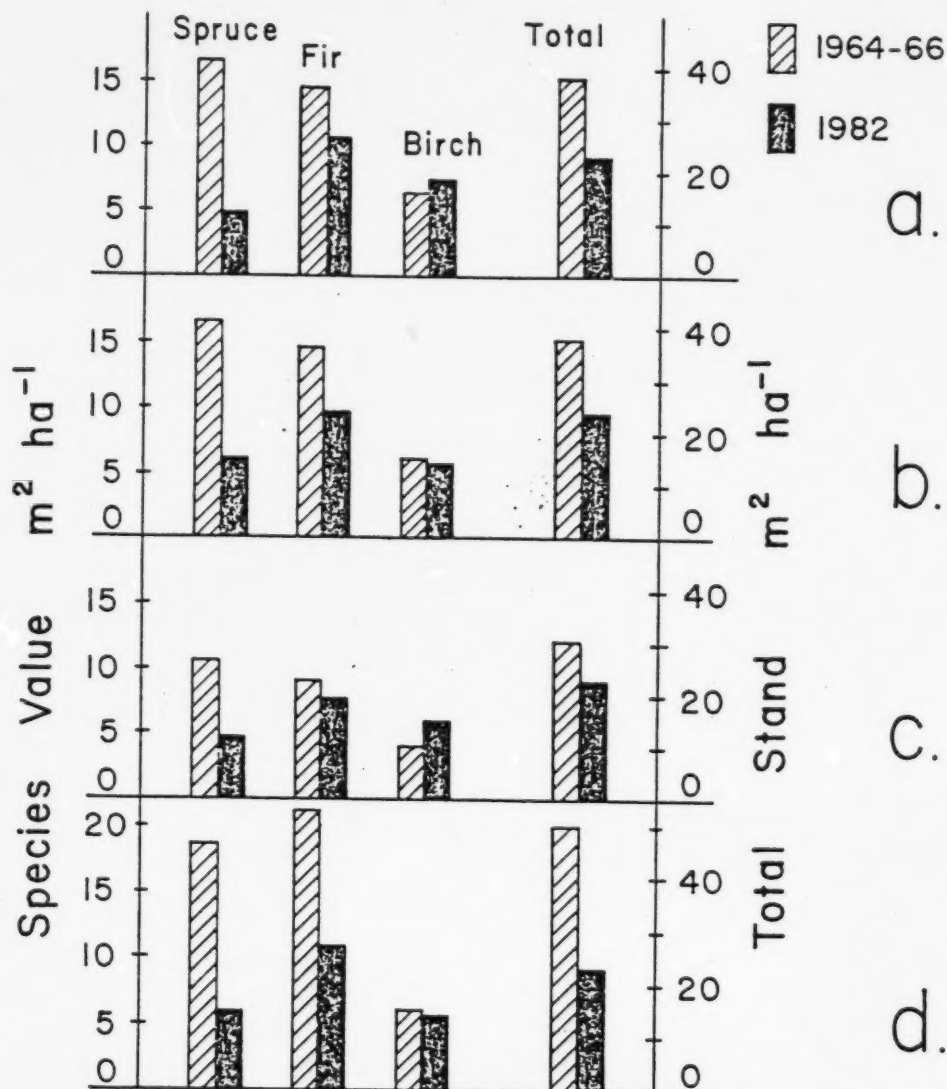


Fig. 1. Basal area ($m^2 ha^{-1}$) for trees ($\geq 10cm$ dbh) of the high elevation ($\geq 900m$) stands on Whiteface Mountain for surveys taken in 1964-66 (hatched bars) and 1982 (solid) for groupings of: (a) all 20 high elevation stands; (b) 11 stands of certain re-location (category 1 see "Methods"); (c) 11 undisturbed stands; and (d) 5 stands which were catastrophically disturbed prior to the resurvey. Plots (c) and (d) include only stands in which the confidence of re-location was "certain" and "highly confident" (both categories 1 and 2). The scale on the left is for basal area of individual species (spruce, fir and birch) while the scale on the right applies to the sum for all species in the stand (far right bars).

survey. Note that in Fig. 1 the bar graphs are absolute values while the tables are for changes over the time period.

In Fig. 1a and Table 1a all 20 high elevation stands are included regardless of confidence of location, disturbance or slope

aspect. The most significant change is the decrease in basal area of red spruce of $11.7m^2 ha^{-1}$, which is 71% of the original value. The decrease in balsam fir is less, but still significant. The absolute change in basal area of cordate-leaved birch is fairly

Table 1. Change in basal area ($\Delta m^2 ha^{-1}$) and per cent change of the tree component (≥ 10 cm dbh) of the high elevation (≥ 900 m) stands on Whiteface Mountain between surveys taken in 1964-66 and 1982 for the same groupings as Fig. 1. The far right column is the per cent of the total change accounted for by the change in red spruce.

	Red Spruce	Balsam Fir	Total	Change in Spruce as % of Total
a. All 20 high elevation stands (≥ 900 m)				
$\Delta m^2 ha^{-1}$	-11.7	-5.0	-15.4	
% change	-71	-35	-50	76
b. 11 stands of "certain" re-location				
$\Delta m^2 ha^{-1}$	-11.3	-3.2	-14.4	
% change	-69	-22	-37	78
c. 11 undisturbed stands of "certain" and "highly confident" re-location				
$\Delta m^2 ha^{-1}$	-7.6	-1.0	-7.1	
% change	-61	-9	-24	107
d. 5 disturbed stands of "certain" and "highly confident" re-location				
$\Delta m^2 ha^{-1}$	-12.7	-10.9	-27.0	
% change	-69	-50	-53	47

small and probably spurious. The large decrease in spruce accounted for 76% of the decrease for the total sample.

In the 1964-66 survey only "mature" stands were sampled. In general, this meant that highly disturbed or young stands were avoided, but it is possible that stands with spruce were selected while those with a large amount of birch were not. If the original site was not found, in the second survey it is possible that lower amounts of spruce and higher amounts of birch would be measured in the re-survey. To examine this possibility, data for only those high elevation stands of "certain" location are averaged in Fig. 1b and Table 1b. The large per cent decrease in spruce is unchanged, whether surveying all 20 high elevation stands or just those (11 stands) of "certain" relocation; the change in spruce represents 78% of the total decrease.

Five of the sites, including four of the category 1 stands in (b), had been catastrophically disturbed at some time between the two surveys, leading to the suspicion that the spruce decline may be caused by community dynamics. In these stands, dead trees of all common species are mostly toppled over. Some are broken but others are uprooted. Only a few live older trees remain. Two decades ago these shady forest floors were covered with mosses and alpine herbs. They are now stands of open or discontinuous canopies with a dense cover of balsam fir seedlings and saplings with

scattered moss and herbs. The mechanism of disturbance is probably similar to that described by Sprugel (1976) and Sprugel and Bormann (1981), but the wave-like character they observed probably is not as well-defined in these spruce-fir forests (900m-1100m) as it is in the fir forests at higher elevations (>1100).

Data for 16 high elevation stands where location in the re-survey is designated as "certain" and "highly confident" (category 2 summed) are given for undisturbed (c) and disturbed stands (d) in Fig. 1 and Table 1. The absolute decrease in basal area for spruce of $7.6 m^2 ha^{-1}$ is lower in the undisturbed stands (c) than for the other categories but still represents a decrease of 61%. For the disturbed stands (d) the decrease of $12.7 m^2 ha^{-1}$ in basal area is only slightly higher than for (a) and (b). The decrease in red spruce is 107% of the total change for the undisturbed stands, but only 47% for the disturbed stands where the decrease in balsam fir is large. It is clear from Table 1 and Fig. 1 that spruce decreased about the same amount regardless of disturbance or certainty of relocating the stands at high elevations. On the other hand, the decrease of balsam fir is significantly higher for the five disturbed stands (d) than for the undisturbed sub-sample (c), illustrating that natural disturbance is the major cause of the decreases of fir in (a) and (b).

Montane acid deposition from low pH

cloud moisture and rime icing is known to be large (Lovett *et al.*, 1982). They are higher and extend to lower elevations on the west than east side of Whiteface Mountain (Holway and Scott, 1969; Falconer and Kadlecik, 1980). To examine whether such effects are detectable in the vegetation, the high elevation stands were divided into 10 east and 11 west facing sub-samples. No significant differences were found in any of the three major species with the decrease in spruce being 71% and 69% for east and west sites, respectively.

Tree seedling and ground flora frequency were summarized for the same categories as in Table 1 and divided into high and low elevation stands. There were no detectable differences between surveys for all species except that seedling frequency of red spruce decreased by 80% for the high elevation stands. It was unchanged for low elevations. This decrease in spruce seedling amount was found for all elevations by Siccama *et al.* (1982) and may be caused by whatever has produced the decline of the mature spruce trees in Table 1.

Examination of the stands where few spruce seedlings occur showed that, although sparse, there are enough healthy seedlings to carry this shade-tolerant long-lived species through the present decline. The sparse seedling frequency may be due to the high density of balsam fir which is a prolific seeder and perhaps also to the reduction of seed material as the older spruce are stressed by whatever caused the

decline. We postulate that as the balsam fir are naturally thinned out the spruce seeds will compete more vigorously and that most of the existing young seedlings will survive.

In Table 2 the low elevation sample is broken into three categories of confidence in re-locating the stands. There were only three stands where we deemed the re-location as "certain" (category 1), four as "highly confident" (category 2) and five as "uncertain" (category 3). The per cent change of red spruce increases (a. to c.) with degree of confidence in finding the original sites; so does the change in spruce as a per cent of total change in the stand. The decrease in balsam fir and increase in paper birch are probably spurious but could also be natural. Older fir trees in several of these stands were dead or fallen and the birch increase may be due to increase in growth in gaps left by the dead spruce and fir. The decreases in yellow birch in Table 2a and 2b may be real since many old trees of this species were dead. The indicated changes in maple and beech are probably spurious since the absolute values are small.

Discussion. Over the 16–18 year period studied (1964–1982), red spruce has declined by 60–70% in the high elevation spruce-fir forests on Whiteface Mountain and by about 40–60% in low elevation stands. Due to difficulties in finding the original sites this decline for low-elevation sample is less certain than for the high elevation forests, but probably real.

Table 2. Basal area ($m^2 ha^{-1}$) and per cent change for low elevation (<900m) stands on or near Whiteface Mountain for surveys taken in 1964–66 and 1982 for (a) all twelve stands resurveyed (all categories); (b) seven stands where the confidence of re-location was "certain" and "highly confident" (categories 1 and 2) and (c) three stands where the confidence of re-location was "certain" (category 1). The far right hand column gives the per cent of the total change accounted for by the change in red spruce.

	Red Spruce	Balsam Fir	Paper Birch	Yellow Birch	Sugar Maple	Beech	Total Stand	Change in Spruce as % of Total
a. 1964-66	9.3	9.3	4.4	5.2	2.8	2.6	37.6	
1982	5.4	7.7	4.9	3.9	1.5	2.4	28.3	
% change	-42	-17	+11	-25	-46	-8	-25	42
b. 1964-66	11.0	9.7	6.4	6.6	0.6	—	36.6	
1982	6.1	8.4	7.6	4.3	0.8	0.7	30.1	
% change	-45	-13	+19	-34	+33	—	-18	75
c. 1964-66	14.9	9.5	5.9	5.6	—	—	38.8	
1982	5.5	7.2	8.0	5.8	0.6	—	29.4	
% change	-63	-24	+36	+4	—	—	-24	100

Decrease in balsam fir by 35% from the number in the original survey is due to natural disturbance in at least five of the high elevation sites. Forests of this short-lived species are subject to catastrophic breakdown over periods of about 70–100 years (Sprugel, 1976; Sprugel and Bormann, 1981). Changes in other species are too small to state that they are not within the sampling error.

The cause for the spruce decline has been discussed by others (Siccama *et al.*, 1982; Vogelmann, 1982; Tomlinson, 1982, 1983; Johnson and Siccama, 1983). Briefly, the explanations for the decline include three which are natural (community dynamics, pathogens and drought stress) and one which is man-produced (stress from atmospheric contaminants such as acid deposition and heavy metals).

As we show above, stress from community dynamics, in this case natural wind-related disturbance, produces the decrease in balsam fir, but does not account for the decline in spruce even in the high elevation stands.

Siccama *et al.* (1982) concluded that pathogens were not likely the primary cause of the spruce decline in the Green Mountains of Vermont. In the summer of 1983 the first author attended a field trip of plant pathologists and forest ecologists, organized by P. Wargo of the Northeast Forest Experiment Station, to several locations in the northeast including Whiteface Mountain. Secondary pathogens such as *Armillaria mellea* were found on dead or dying trees but not on those nearby which were healthy. The general conclusion was that secondary pathogens were killing the trees after some severe weakening by an environmental stress, a conclusion further discussed by Johnson and Siccama (1983).

Drought has been implicated in earlier declines of this species (McIntosh and Hurley, 1964), and Hopkins (1980) has reported several unexplained 19th century spruce declines in the northeastern U.S. Johnson and Siccama (1983) reported that forty per cent of red spruce tree ring cores taken from stands in the northeastern U.S. forests show an abrupt decrease in ring width beginning in the mid-1960's. This corresponds to the timing of a drought which was extensive throughout the eastern U.S.

from 1962–65 (Namias, 1966). Summer rainfall at 585m on Whiteface Mountain was 35%, 10% and 39% below normal for 1964, 1965 and 1966, respectively. While records were not taken at Whiteface in 1963 the summer rainfall was from 25–50% below normal in nearby Adirondack locations. The Palmer index indicated severe drought in 1963 for Vermont stations and very dry from 1962–65 (Johnson and Siccama, 1983). Tomlinson (1982, 1983) has suggested, based partly on results of studies by Ulrich and his colleagues in Germany (Ulrich, 1983), that acidity effects can be coupled with drought periods to produce increased stress on the fine root systems of the trees.

Observations of soil pH by our group in 1964–66 (Holway and Scott, 1969; Witty, 1968) showed that the organic layers, which contain most of the fine roots, have had pH values lower than that deposited in rainfall and as low as that in cloud catch and rime ice (Falconer and Kadlecsek, 1980; Lovett *et al.*, 1982). Typical pHs of the organic matter layers in 1965 were 3.0 to 4.0 while the cloud catch pH was from 2.7 to 6.2. Average summer cloud pH, unweighted for water content, is about 3.8. While this evidence does not rule out the effects of acid deposition on the spruce decline, it does point out that at least at higher elevations the vegetation has survived in highly acid conditions.

Conclusion. The most important result of the re-survey is that red spruce has declined significantly over the past two decades. The decline appears to be general over all altitudes, vegetation types, and size classes but was greater at high than low elevations. The decrease in spruce appears to be part of a classic decline in this species which seems to be occurring over the northeastern U.S. (Siccama *et al.*, 1982; Johnson and Siccama, 1983).

Catastrophic disturbance, common in these montane forests with high amounts of balsam fir, can be ruled out as the cause of the spruce decline. There is no evidence that primary pathogens are involved although secondary pathogens are probably killing the trees following some other major stress. Drought, acid deposition and ac-

cumulation of heavy metals or other pollutants either singly or in combination can still not be ruled out.

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